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Management of soil organic matter and carbon storage in tropical fruit crops

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ABSTRACT

The main objective of this study was to investigate changes in carbon dynamics and stocks in agricultural soils. Soil samples were collected at 0-10 cm and 10-30 cm depths in two agricultural areas (cultivated with banana (*Musa* spp.), and cultivated with citrus (*Citrus sinensis*). A native forest soil was used as a reference and to determine the carbon pool management index. Organic matter was physically fractionated into particulate organic matter (> 53 μm) and complexed organic matter (< 53 μm). Analysis of total organic carbon was run to characterize soil organic matter. Comparing to the native forest soil, the banana cultivation increased the total soil organic carbon content (TOC) in approximately 14% while citrus cultivation reduced the TOC content in about 38%. The cultivated soils reduced the particulate organic matter fraction in more than 50%, showing a higher decomposition rate of the organic residues. The Carbon Management Index values were lower than 1 in all treatments, however the best results were observed for the citrus orchard (116.5). Overall, the change in land use from native forest to fruit crops reduced soil organic matter content, especially its labile fraction, and reduced soil quality.

Palavras-chave:
matéria orgânica particulada
qualidade do solo
sequestro de carbono
solos tropicais

Manejo da matéria orgânica do solo e estoques de carbono em cultivos de frutas tropicais

RESUMO

Com este trabalho objetivou investigar as mudanças na dinâmica e no estoque de carbono em solos agrícolas. Amostras de solo foram coletadas de 0-10 cm e 10-30 cm, em duas áreas agrícolas (cultivo de banana (*Musa* spp) e cultivo de citros (*Citrus sinensis*). Um solo em floresta nativa foi utilizado como referência e para determinação do Índice de Manejo de Carbono (IMC). A matéria orgânica do solo (MOS) foi fracionada fisicamente em particulada (MOP, > 53 μm) e complexada (MOC, < 53 μm). O carbono orgânico total (COT) foi analisado para caracterizar a MOS. Comparando com o solo em mata nativa o cultivo da banana aumentou o teor de carbono orgânico do solo (TOC) em aproximadamente 14% enquanto o cultivo de citros reduziu o teor de TOC em cerca de 38%. O cultivo de fruteiras reduziu a fração particulada em mais de 50% mostrando uma velocidade de decomposição maior dos resíduos orgânicos. Os valores do Índice de Manejo de Carbono foram menores que 1 em todos os tratamentos; entretanto, foram observados os melhores resultados para o pomar de citros (116,5). No geral, a mudança no uso da terra de mata nativa para culturas de frutas reduziu o teor de matéria orgânica do solo, especialmente sua fração lábil, e a qualidade do solo.

Introduction

The conversion of native forest into agricultural areas, especially in the northeast region of Brazil, has significantly increased in order to meet the growing demands for food and other products. The change in land use along with the humid and warm climate conditions reduced the soil organic matter natural reserves (Netto et al., 2007) and changed soil organic matter dynamics (Bona et al., 2008). Besides the deleterious effects on soil quality, this continuous loss of organic matter is of great concern due to the greenhouse gas emissions (Lal, 2004).

Soil organic matter is the primary source of, and a temporary sink for, plant nutrients in cultivated soils. Its importance in maintaining soil tilth, aiding the infiltration of air and water, promoting water retention, building soil aggregation, and controlling the fate of applied pesticides is well known (Srinivasan et al., 2012). However, despite all its benefits, the maintenance and build up of the soil organic matter levels in agricultural areas is a major challenge in the very weathered soils of the tropical regions. This is due to different inputs of organic residues and fertilizers, which influence soil microbial activity and mineralization rates. Moreover, the sandy nature of the soil, soil tillage, moisture, and temperature are also important factors that influence organic matter dynamics, composition and accumulation in soil.

Different fractions of soil organic matter pool respond differently to management practices due to the composition and association with the mineral matrix, which influence the accessibility to decomposers and the stability in the soil environment (Gregorich et al., 2006). The labile fraction is easily decomposable. Its relative amount and the degree to which it is protected determine its degradability (Wendling et al., 2010). The more stable and recalcitrant fraction of soil organic matter contains more processed degraded material and it is associated with soil mineral to form organic-mineral complexes (Wiesenberg et al., 2010). The stable fraction is a major sink for C storage and contains little mineralizable C (Jagadamma & Lal, 2010).

Changes in soil organic matter fractions as a function of land use change have been used to evaluate organic matter dynamics and to quantify C stocks (Bongiovanni & Lombartini, 2006; Ashagrie et al., 2007; Galdos et al., 2009). Cambardella & Elliott (1992) developed an operationally define fractionation method that separates soil organic matter into two fractions: particulate organic matter (POM) and complexed organic matter (COM). POM (sand-size fraction, > 53 μm) is the labile fraction that is composed of readily available material, more sensitive to changes in land use, and can contribute to soil fertility through nutrient cycling. Due to its lability, POM is highly susceptible to decomposition, thus constituting a fragile C reserve in soil. In contrast, COM (silt- and clay-size fraction, < 53 μm) is a more stable C fraction associated with soil minerals, has a lower turnover rate, and can be related to C sequestration.

The particulate organic matter can be used to determine index values that measure the organic matter lability (Vieira et al., 2007) and can be related to soil quality. The Carbon management index (CMI) relates the carbon pool index (CPI) and the lability index (LI) in order to better explain changes in soil C dynamics as a function of changes in land use and management (Assis et al., 2010). In order to determine these indices, it is imperative to have native forest soils as reference since POM, in the reference soil, must enter into the calculation. High CPI and LI values may indicate good soil conditions (Wendling et al., 2008). Carbon management index has been used in studies that monitor both soil degradation and agricultural yields (Blair et al., 1995; Wendling et al., 2008).

There are very few studies on the effects of forest conversion to agricultural areas on the levels of labile C fractions, C stocks and C management index in the northeastern Brazil. Therefore, the objectives of this study were (i) to evaluate the effect of different land uses (native forest, citrus and banana) on the total soil organic carbon and soil organic matter fractions and carbon stocks of a Brazilian Ultisol from the Coastal Tablelands in the estate of Sergipe, (ii) to determine the Carbon Management Index (CMI) for those land uses based on physical fractionation data.

Material and Methods

The study was conducted during August and October 2010 in the irrigated perimeter of the Platô de Neópolis, State of Sergipe (site coordinates: 10° 19´ 12´´ S, 36° 34´ 46´´ W), in northeast Brazil. The climate of the region is type BSh' according to Koppen-Geiger classification (Peel et al., 2007), with dry summers and rainfall concentrating in the months of May to September. The mean annual precipitation and temperature are 1200 mm and 30 °C, respectively. The studied soils were classified as Ultisols (typic Hapludult) of the Soil Survey Staff.

The study was carried out in a completely randomized design, in a factorial scheme, with 3 types of land use and 2 depths of sampling (0-10 cm and 10-30 cm), with 3 replications. Two areas cultivated with banana and citrus plants for eight years were evaluated and compared with an area under native forest, as reference. Both orchards are periodically irrigated. The citrus orchard (*Citrus sinensis* L. Osbeck), orange pear was implemented using the 6 x 4 m spacing (416 plants ha^{-1}), and it was conventionally managed, with application of mineral fertilizer and pesticides. Weeds were controlled using mechanical operations (mowing), and irrigation was performed via central pivot. The banana Prata orchard (*Musa* spp) was implemented using the 3 x 3 m spacing (1.111 plants ha^{-1}) and received mineral and organic fertilization. Crop residues were usually disposed in the inter rows after fruit harvest. Irrigation was performed via micro sprinkler system. The native vegetation, located nearby, was a remnant of the Atlantic Forest.

Each experimental area was divided into three experimental plots of 100 m^2, selected by similarity and uniformity of topography, soil order and textural class. In each experimental plot, ten simple soil samples were randomly collected at each depth and mixed to obtain a composite soil sample. The soil samples were homogenized and transported in plastic bags to the laboratory, air dried, sieved through a 2-mm screen and stored for posterior analysis. Soil bulk density was determined by the core sampling method using a volumetric cylinder. The ratio of oven-dry weight of the soil (dried at 105 °C for 24 h) core and its total volume was expressed as soil bulk density.

It was used an operationally defined fractionation method to determine soil organic matter fractions, according to Cambardella & Elliot (1992). This method separates total organic matter into two fractions: Particulate organic matter (POM) and complexed organic matter (COM). The air-dried soil samples were 2 mm sieved. Of these, 20 g were placed in plastic bottles (volume of 250 mL) and 70 mL of sodium hexametaphosphate added at a concentration of 5.0 g L^{-1}. The mixture was shaken for 15 h in a horizontal shaker, at 130 oscillations min^{-1}. After this process, the entire content of the vial was placed in a 53 μm sieve and washed with a weak jet of distilled water. The material retained on the sieve, defined as total particulate organic matter (> 53 μm), was dried at 50 °C. After drying, the sample was ground in a porcelain mortar and passed completely through a 0.149 mm sieve. Then aliquots were weighed and analyzed for their C contents, representing the particulate organic carbon (POM) (Cambardella & Elliot, 1992).

Total soil organic matter was determined through the wet acid digestion Walkley-Black method (Nelson & Sommers, 1996).

Soil organic carbon stock was calculated using the concentration of the total soil organic carbon (TOC) and the result of soil bulk density of each layer (Bernoux et al., 2002), using the Eq. 1:

$$\text{Cstock}\left(\text{Mg ha}^{-1}\right)=\frac{\text{TOC}\times\text{Ds}\times\text{e}}{10} \quad (1)$$

Where TOC (g kg^{-1}) is total organic carbon at a given soil depth (thickness of the layer); Ds (kg dm^{-3}) is the soil bulk density at a given soil depth (thickness of the layer); and e is the thickness of the layer (cm). To cope with differences in soil mass at each layer, the C stock data were corrected according to formula suggested by Sisti et al. (2004).

Based on the TOC in the native forest (reference) area and in the agricultural areas, a carbon pool index (CPI) was created and estimated as follows: CPI - TOCagricultural area/TOCnative forest. According to changes in the proportion of labile (POM) and non labile (COM) organic C (CL and CNL) in the soil (i.e., L = CL/CNL), a lability index (LI) was calculated as LI - Lagricultural area/Lnative forest. These two indices were used to determine the carbon management index (CMI), according to the following Eq. 2:

$$\text{CMI}=\text{CPI}\times\text{LI}\times 100 \quad (2)$$

Results were expressed as mean of three replicates and presented with confidence interval of 5%. Such procedure was applied considering the assumption of the existence of pseudo-repeat, according to Millar & Anderson (2004).

Results and Discussion

Considering the soil under native forest, the irrigated perennial banana cultivation increased the total soil organic carbon content (TOC) in approximately 14%, in the top 10 cm soil layer. On the other hand, the irrigated perennial citrus cultivation reduced the TOC content in approximately 38%, in the same soil depth (Table 1). The reduction in the TOC content was observed with depth in all soil uses, showing a general decreasing tendency. In this study, TOC was effective in showing changes in soil caused by land use and management. Differences in TOC content in the two orchards are explained by the amount of crop residues disposed on the soil surface as well as the plant canopy. In addition, crop residues are scarce and limited to falling old leaves in the citrus orchard. The degradation is therefore due to the reduced input or recycling of organic materials and higher disturbance of soil due to the soil management practices. However, in the banana orchard, the greater plant canopy and the amount of crop residue contributed to the increase in the accumulation of soil organic matter. Factors contributing to high TOC in native forest include high inputs of organic residues and a low degree of soil disturbance.

Table 1. Total soil organic C, particulate organic matter carbon (POM) and percent of POM at 0-10 and 10-30 cm depth, of a Yellow Ultisol under banana and citrus cultivation, and under native forest in the irrigated perimeter of Platô de Neópolis/Sergipe, Brazil

Land use	Total organic C (g kg^{-1})	POM (g kg^{-1})	POM/TOC (%)
Depth 0-10 cm			
Banana	14.0 ± 1.69	1.84 ± 0.36	13.4 ± 4.02
Citrus	7.57 ± 0.13	1.80 ± 0.05	23.8 ± 1.12
Native forest	12.3 ± 0.41	4.32 ± 0.62	35.2 ± 4.72
Depth 10-30 cm			
Banana	6.69 ± 0.58	1.37 ± 0.11	20.4 ± 0.19
Citrus	3.80 ± 1.15	1.55 ± 0.12	43.0 ± 14.20
Native forest	6.08 ± 0.57	2.05 ± 0.72	34.5 ± 15.69

Values are mean ± Confidence Interval (IC) at 0,05 level of probability

It is important to point out that, overall, even in the soil under native forest, TOC content is low. This is because of the very sandy nature of the Ultisol that is being evaluated as well as the warm climate of the region, factors that stimulate organic matter decomposition and loss.

The distribution of soil C in labile and stable fractions, compared to a reference system (native vegetation), can also provide relevant information regarding the state of soil organic matter of agricultural systems (Blair et al., 1995). Labile fraction of the soil organic matter, defined here as particulate organic matter (POM), ranged from 1.37 to 4.32 g kg^{-1} (Table 1). In the native forest soil, the contents of POM in the top soil and in the 10-30 cm depth were 58 and 29%, respectively, greater than in the cultivated soil. More POM under native forest with larger, longer living roots than under cropland is probably related to the root-derived products (Franzluebbers & Stuedemann, 2002). Even though the soil cultivated with banana presented greater amount of TOC than the native forest, only 13.4% is labile, in the form of POM, showing a higher decomposition rate as well as less influence of root residues and exudates. The same trend was observed in the citrus cultivated soil, but to a less extent. The higher decomposition rate observed in the cultivated soils is probably due to liming and to an improved nutrient balance as a function of fertilizer application. Liming reduces soil acidity. Fertilizer application in cultivated soils reduces C/N ratio and increase the availability of nutrients. Both practices can potentially increase microbial activity and stimulate organic matter decomposition, resulting in less labile fractions in the soil.

In general, there was a decrease in POM concentration with depth, a normal trend since TOC also decreased with depth. The proportion of POM-C to TOC followed the order native forest > citrus > banana, in the topsoil layer, and ranged from 13.4 to 35.2%, higher than the range reported by Handayani et al. (2010). Percentage of POM in the native forest soil did not change with depth. However, the cultivated soil increased the percentage of the labile organic matter. This is probably due to an increase in soil density with depth in the cultivated soil, reducing aeration and decomposition of the soil organic matter.

Stable soil organic matter fraction (complexed organic matter - COM) comprised 65 to 87% of total soil organic carbon in the evaluated areas. At the surface layer, cultivated soil presented higher proportion of stable organic matter than natural forest soil. The higher amount of the stable fraction of organic matter is important to the accumulation of C in the soil system, since this form of C is protected in organo-mineral complexes. According to Wu et al. (2005), addition of fertilizers and organic amendments increases the organic carbon associated with different particle size fractions, and alters the allocation of C among fractions.

Total carbon stocks followed the order banana > native forest > citrus in both soil layers (Table 2). Values varied from almost 12.0 Mg ha^{-1} to as high as 21.0 Mg ha^{-1}. Besides climate and soil texture, C sequestration is affected by N fertilization as well as the retained time of residue on the soil surface. More important than the total amount of C sequestered into the soil is the quality of the C. The amount and composition of soil organic matter fractions impact aggregation that in turn physically protects the C from degradation, increasing the mean residence time of C (Gregorich et al., 2006; Srinivasan et al., 2012). In this study, more than 60% of the soil carbon was stored in stable C forms, not readily available to decomposition. It is interesting to note that cultivated soils were able to store more C under stable forms than the native forest soil.

The higher C stocks in the physical fractions of the soil under banana cultivation express the significant potential of that crop system to increase the organic matter content and promote C sequestration.

It is well known that native forest soil C levels reflect the balance of C inputs and C losses under native conditions such as productivity, moisture and temperature regimes. The results of this study confirm that C levels in native soil do not necessarily represent an upper limit in soil C stocks. The higher levels of C in soil cultivated with banana are evidence that C levels in intensively managed agricultural ecosystems can exceed those under native conditions.

The Carbon Management Index (CMI) shows the influence of land use on the TOC levels. Values below or above 100 indicate either a negative or positive impact on TOC content and soil quality, respectively (Bona et al., 2008). Determination of the CMI is related to the carbon pool index (CPI) and the Lability index (LI), both indices are calculated with reference values obtained from native forest soils.

The values of Lability Index (LI) obtained from labile C estimated by particle-size fractionation varied from 0.5 to 1.5 (Figure 1B), being the values higher at depth than at the soil surface. This result reflects the higher values of the particulate organic matter at depth. Also, lability index was higher in the citrus soil than in the banana soils, although C pool index reached higher values in the banana soils.

According to results of CPI and LI, the citrus soil showed higher CMI than the banana soil (Figure 1C), which is amended essentially with crop residues (stem and leaves) disposed at

Table 2. Carbon stocks (Cc), and particulate (POM) and complexed organic matter (COM) C at 0-10 and 10-30 cm depth, of a Yellow Ultisol under banana and citrus cultivation, and under native forest in the irrigated perimeter of Platô de Neópolis/Sergipe, Brazil

Land use	Cc stock	POM stock	COM stock
	Mg ha^{-1}		
Depth 0-10 cm			
Banana	22.8 ± 1.80	3.00 ± 0.33	19.80 ± 3.17
Citrus	12.3 ± 3.61	2.90 ± 0.36	9.40 ± 0.30
Native forest	18.5 ± 1.84	6.50 ± 2.34	12.00 ± 0.88
Depth 10-30 cm			
Banana	21.8 ± 1.83	4.50 ± 0.33	17.30 ± 1.54
Citrus	12.4 ± 3.62	5.10 ± 0.36	7.30 ± 4.09
Native forest	19.7 ± 1.84	6.67 ± 2.35	13.00 ± 4.17

Values are mean ± Confidence Interval (IC) at 5%

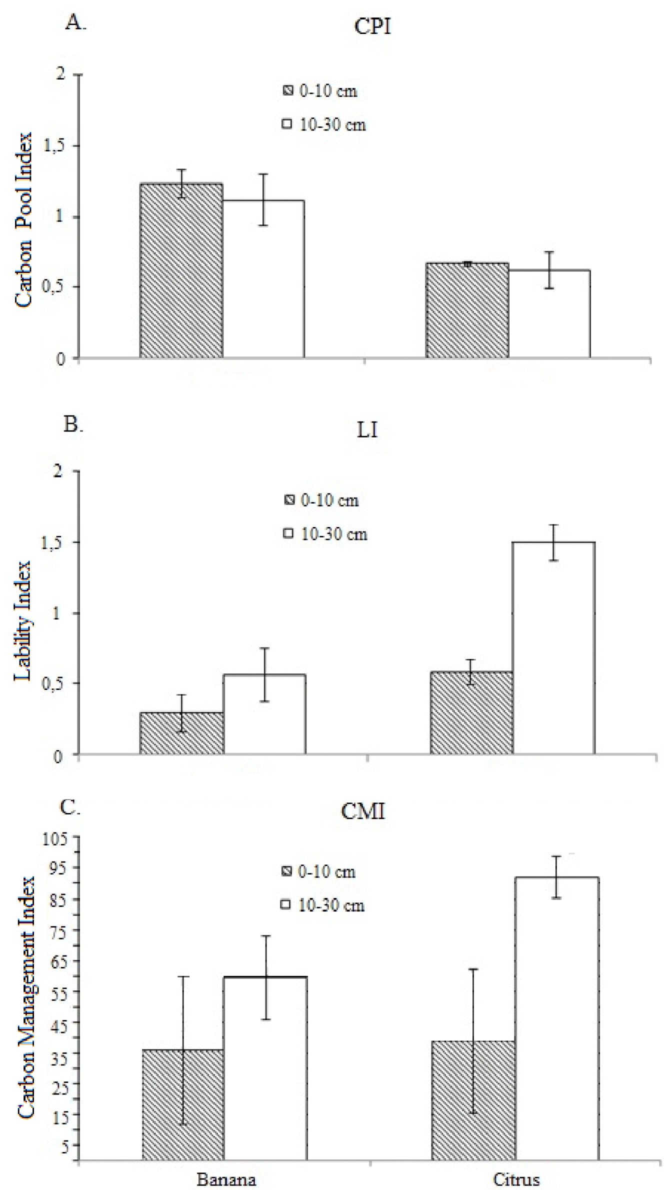

Figure 1. Carbon pool index (CPI - A.), lability index (LI - B.) and Carbon management index (CMI - C.) at layers 0-10 and 10-30 cm depth, of a Yellow Ultisol under banana and citrus cultivation, and under native forest in the irrigated perimeter of Platô de Neópolis/Sergipe, Brazil. The vertical bars represent the standard errors

the soil surface. In the citrus orchard, organic residues come from a variety of weeds that cover the soil most of the year, with contributions from the root systems, being most prone to decomposition. Therefore, the higher Lability index in citrus orchard determined a higher CMI in that soil (over 90%). However, CMI values still are below 100, indicating reduction in soil quality in both orchard soils..

The change in TOC pool size as affected by land use can be expressed using the carbon pool index (CPI), which is calculated from sample total C (TOC in the cultivated soil) expressed as a fraction of the reference total C (TOC in the native forest soil) (Blair et al., 1995). Lower CPI values indicate higher organic C loss. CPI > 1 also indicates aggradation in soil quality as related to soil organic matter content and to all benefits of this component for soil improvement. In this study, soil under citrus cultivation presented lower CPI values as compared to the soil cultivated with banana reflecting a higher reduction in the total C pool under citrus cultivation (Figure 1A). Also, CPI values were < 1 in citrus soil. In contrast, CPI values in banana soil were > 1. Those results are similar to those reported by Blair et al. (1995) for conventional tillage system and weedy fallow soil.

In order to determine the CMI, it was calculated the lability index (Figure 1B). This index relates the lability of soil organic matter in cultivated soils to that in native forest soils. The LI was very low (0.29) in the banana topsoil layer, a reflection of the low percentage of POM. In contrast, LI was very high (2.05) in the 10-30 cm layer in the soil cultivated with citrus. In general, LI increased with depth.

Considering the close relation among soil organic matter and physical, chemical and biological characteristics of tropical soil, it is hypothesized that the CMI would also give indications about the soil quality in different land uses. In this study, change in land use from forest to agricultural presented a negative effect on soil quality, as presented by the values of the CMI (Figure 1C), except for the 10-30 cm layer of the soil cultivated with citrus (CMI = 116.5). In the topsoil layer, the cultivated soil presented low and similar CMI (34.0 - 37.8). Similar results were reported by Assis et al. (2010) when they evaluated CMI in soils under perennial and annual cultivation, in an irrigated perimeter. The authors related their results to the negative effect of the substitution of natural vegetation with crops, mainly on the soil surface. Even though CPI values were higher in the soil cultivated with banana, the lower LI significantly reduced the CMI. It is interesting to point that, CMI integrated two important characteristics, the quantity and the quality of the soil organic matter. The greater TOC content of the banana soil was due to the frequent addition of organic residues in banana plantations. According to Borges et al. (2008), approximately 66% of the banana tree vegetative mass is returned to the soil, mainly after fruit harvest.

Changes on the Lability Index among treatments were higher than changes on the Carbon Pool Index (Figure 1A and B). These results are similar to those reported by Whitbread et al. (2000) and Diekow et al. (2005). According to the authors, soil organic matter lability parameter gives to the CMI the capacity to detect changes on soil organic matter status more efficiently than when evaluating soil organic C stocks.

Conclusions

1. The conversion of the native forest soil to fruit crops in the Plato de Neópolis, State of Sergipe, changed the total soil organic matter content and, most important; changed the susceptibility of the soil organic matter to decomposition and loss.

2. Physical fractionation of the soil organic matter was effective in showing changes in land use since the labile fraction of the soil organic matter was reduced in the fruit crops soil.

3. Even though the Carbon Management Index was not higher than 1 in any of the land uses, the higher lability index in the citrus orchard caused the CMI be higher in that area.

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